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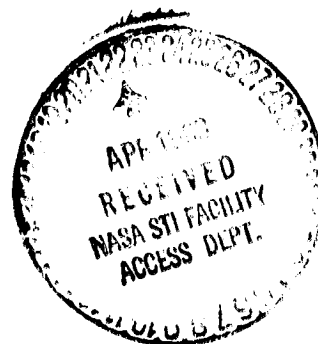
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SUMMARY

A review of investigations for many missile configurations coupled with numerous possible mission requirements indicates that some fundamental considerations can lead to definite areas of missile/mission compatibility. For example, a wingless missile or a missile with relatively small wings may take advantage of low minimum drag and accomplish missions where fast fly-out time is important. Such missiles, however, are generally found to be satisfactory from a maneuverability standpoint only under conditions of relatively low altitude and/or high speed, or when nearly ballistic fly-out paths can be used against essentially non-maneuvering targets.

For high maneuverability, an efficient lifting surface is beneficial together with linear stability characteristics and high control effectiveness. It has been found that these criteria can be met with various design arrangements that may employ aft tail, wing, or canard controls and that, through careful design, each of these control types can result in desirably low hinge-moment characteristics.

Wing control missiles may produce erratic aerodynamic behavior, particularly at angle of attack, because of flow field effects induced over the tail. However, through careful design, wing control missiles may provide adequate maneuverability at relatively low angles of attack for some missions while offering potential advantages related to seekers, air inlets, and induced flow fields.

Cruise missile configurations vary somewhat in detail but the dominant factor is an aerodynamically efficient design that is commensurate with the required weight and the desired range.

INTRODUCTION

Many tactical and strategic missions can be accomplished through the use of aerodynamic missile systems. These varied missions may require missile systems that operate as surface-to-air, surface-to-surface, air-to-air, and air-to-surface, including both the short-range tactical systems and long-range cruise strategic missile systems. A seemingly endless variety of missile configuration concepts are possible for use in meeting the requirements for various missions. It is the purpose of this paper to discuss, from an aerodynamic point of view, various missile configuration concepts with a view toward determining the most suitable geometric arrangements for the different mission applications. Many new missile systems are under study and

the overall objective of current NASA research programs is to determine means whereby missile performance might be improved in terms of maneuverability, aerodynamic efficiency, aerodynamic range, and design simplicity. Aerodynamic systems have received the most attention primarily because of the potential for increased reliability and the probability of lower cost of the less sophisticated aerodynamic concepts.

NASA studies have included foreign and domestic configurations in addition to general research models for the purpose of assessing the performance of the systems and acquiring knowledge for future application. Specific objectives of the studies are to provide a background of aerodynamic data that may be used in performance evaluation, in making various trade studies between differing systems, as an aid in defining maneuver envelopes, to aid in optimizing the aerodynamic characteristics, to improve the loads and structure evaluation techniques, and to provide for the continued development and improvement of experimental and analytical missile study techniques. The approach has been through the use of both analytical and wind-tunnel studies from which such characteristics as the drag, stability, aerodynamic loads, control surface loads and moments, and the control effectiveness parameters are determined.

Among the geometric variables that have been investigated are the afterbody shape, the forebody shape, the wing and tail planform and location, the use of various types of propulsion systems, and the use of various types of control systems including the aft tail, canard arrangements, and wing controls. Only some selected items will be included in this paper for discussion, although an extensive bibliography of reports covering some missile studies is included in references 1 to 67.

SYMBOLS

A	maximum body cross sectional area
a_n	instantaneous normal acceleration, g's
$C_{D,0}$	drag coefficient at zero lift
C_h	hinge moment coefficient
C_L	lift coefficient
C_{L_α}	lift curve slope, per deg
C_m	pitching moment coefficient
C_{m_δ}	pitch control effectiveness, per deg
C_N	normal force coefficient
h	altitude
H.M.	hinge moment
M	Mach number

R	turn radius
S	wing area
W	weight
x_{ac}	aerodynamic center location
δ	pitch control deflection
α	angle of attack

DISCUSSION

Without defining any specific mission requirements, for the purpose of this paper it will be assumed that missions exist that cover ranges from very short visual contact distances to ranges on the order of hundreds of miles. In altitude, it will be assumed that missions may extend from sea level (and sub-sea level) throughout the useable atmosphere to approximately 100,000 feet. Some types of missile missions are illustrated schematically in figure 1. The speed range considered extends from subsonic to supersonic Mach numbers of approximately 5. It will be assumed that for some missions very little maneuvering requirements exist while for other missions exceedingly high maneuvering capability is required. As a point of reference, figure 2 may be used to illustrate, for the case of maneuvering missiles, the interplay between maneuverability, speed, and turn radius for a constant altitude. For a constant g level, as the speed increases the turn radius increases, or as the g increases for the constant speed, the turn radius decreases. The instantaneous g values are obtained for a level-flight constant-altitude case and is defined as being the lift available to the missile divided by the lift required to sustain level flight for the missile. Aerodynamic factors of primary importance to the lift available are the configuration geometric features that affect the ability of the missile to produce lift, the stability characteristics, and the control surface effectiveness. Factors of primary importance to the lift required are the wing loading (or weight), the velocity of the missile, and the altitude.

Observations related to trailing edge flap control missiles. - A comparison of the maximum lift producing capability of a trailing edge flap control missile (ref. 29) and a canard control missile (ref. 24) as a function of Mach number is shown in figure 3. Because of differences in the stability characteristics as well as in the control effectiveness, the lift variation with increasing Mach number is seen to decrease rapidly for the trailing edge flap control and to generally increase with increasing Mach number for the canard control. Only at the lowest Mach numbers does the trailing edge flap missile excel the canard control missile in lift producing capability. A fundamental problem with the trailing edge flap configuration is a loss in lift near the trailing edge with increasing Mach number that is caused in part by boundary layer growth and in part by the wing tip shock induced separation. This loss in lift contributes to a loss in control effectiveness as well as to a nonlinear pitch-up tendency that limits the usable lift range and the usable flap deflections. The canard configuration characteristics were dictated by a progressive forward movement of the center of pressure (reduced stability level) with increasing Mach number caused by the wing lift curve slope change, and by an increase in control effectiveness at high lifts and high Mach numbers caused by the favorable local dynamic pressure

field in the vicinity of the canard surfaces as will be discussed later. A comparison of the instantaneous normal acceleration capability of the two missiles is shown for a Mach number of 2.4 and an altitude of 30,000 feet and for an assumed constant weight. As a result of the differences in the aerodynamic characteristics of the two vehicles the trailing edge flap missile produced a g value slightly in excess of 6, whereas the canard control missile produced a g value of 16. It is interesting to note that this difference in maneuvering capability occurred although the canard missile, having a smaller wing area, did have a wing loading approximately twice that of the trailing edge flap control missile. In addition, the hinge moment values were reduced with the canard configuration by an order of magnitude. The same flap control missile is compared with an aft tail control missile in figure 4 where the pitching moment variation as a function of lift coefficient is shown for a Mach number of approximately 3. Substantial improvements are indicated for the tail control missile in that the pitch-up characteristics have been eliminated and the usable control effectiveness range considerably extended. The effect of these aerodynamic improvements on the effective missile operating envelopes for equal propulsion is shown in figure 5. The boundary of altitude versus range indicates the envelope in which the missile is considered lethal against a target that is flying at a Mach number of 3 and has a 5 g capability at 35,000 feet and a 1 g capability at 80,000 feet. The target performs an evasive maneuver with a 10 second delay (shown on the left) and a 20 second delay (shown on the right) after missile launch. In both instances the effective operating envelope for the aft tail missile is considerably improved over that for the trailing edge flap missile. For the twenty second delay the increase in altitude capability is especially significant. A point to remember concerning the evasive maneuver delay time is that, generally speaking, the longer the delay time, the greater the agility required for the missile in the end-game intercept.

Observations related to aft tail control missiles. - Examples wherein the stability and control characteristics of aft tail missiles were altered through configuration changes are shown in figures 6 and 7. For the two aft tail control missiles shown in figure 6 a change in wing planform from a trapezoid (unpublished) to a delta (ref. 33) resulted in the elimination of a pitch-down tendency and a substantial increase in the maximum lift capability at $M = 4.6$. The change in linearity in this instance is apparently related to the stability contribution of the tails. In figure 7, the linearity for two aft tail missiles with trapezoidal wings was improved through a decrease in body length-to-diameter ratio (reducing the forebody lift influence), and through some rearrangement of the wing and tail locations. Again, the configuration with the improved linearity, should provide considerably improved maximum lift capability.

Observations related to canard control and aft tail control missiles. - Some results from reference 52 are useful in comparing characteristics of canard control and aft tail control missiles. The longitudinal stability and control characteristics for a canard-control missile are shown in figure 8 for various control deflections at $M = 2$ and 4. The canard-control effectiveness shows some decrease with increasing control deflection and with increasing C_L or α at the lower Mach number. Such a result is generally expected since the control deflection and angle of attack are additive and flow separation occurs on the canard surface. A decrease in effectiveness also occurs with increasing M near $\alpha = 0^\circ$ because of the decrease in canard surface-lift curve slope. However, at the higher Mach number, the effectiveness increases substantially with increasing C_L or α because of the changes in local surface pressure on the canard surface--increasing pressure on the compression side and decreasing pressure on the expansion side. Reasonably good aerodynamic potential is indicated at both Mach numbers. For a C_L of 12 and a representative weight loading, W/A , of about 750 pounds

per square feet, for example, a level flight a_n of about 30 is obtainable at an altitude of about 30,000 feet at $M = 2$ and also at an altitude of about 50,000 feet at $M = 4$. A well-designed canard-controlled missile provides a concept that utilizes a small positive control force (small surface area) and takes advantage of a long moment arm to produce the rotation moments.

The longitudinal stability and control characteristics for an aft-tail control missile are shown in figure 9 for various control deflections at $M = 2$ and 4. The control effectiveness at $M = 2$ remains essentially constant with increasing control deflection and increasing C_L or α . Since α and δ are opposite, in this case, the local flow angle at the tail remains small. The control effectiveness again decreases with increasing M near $\alpha = 0^\circ$ due primarily to the decrease in tail lift curve slope. Some decrease in effectiveness occurs at $M = 4$ for an α range to about 10° probably due to a wing-wake effect on the tail. However, at higher angles of attack, as the tail moves below the wing wake and enters the high local dynamic pressure field generated by the compression side of the wing, the tail effectiveness increases dramatically. These results indicate that, for a W/A of about 750 pounds per square feet, a_n values in excess of 40 are potentially available at $h = 30,000$ feet for $M = 2$ and at $h = 50,000$ feet for $M = 4$. Generally speaking, the aft-tail control concept makes use of a relatively large, efficient lifting-control surface with a short moment arm to produce the rotation moments.

The results for the canard-control concept and the aft-tail control concept indicate that both are capable of producing good aerodynamic maneuvering. The design choice between the two concepts may often be related to other factors such as inboard-profile arrangement or carriage and launch constraints.

Some afterbody modifications. - A canard control missile with an exceptionally high length-to-diameter ratio (18.3), reported in reference 45, exhibited a severe pitch-up tendency due to the combined effects of the forebody lift and the canard surface lift. Such a tendency was characteristic of the Nike Ajax missile. Efforts to alleviate this type of instability have been explored through the use of an afterbody flaring or fin/flare combinations. As shown in figure 10 the addition of a slight flare and aft fixed fins resulted in the elimination of the unstable pitching moment characteristic for a constant center of gravity location and resulted in a substantial increase in the usable lift range. The improved stability and maximum lift capability would be reflected in improved g capability and enlarged effective operating envelopes.

Observations related to wings. - A comparison of some of the aerodynamic characteristics of a tail control missile, with and without a wing (refs 33, 41, and 67), is shown in figure 11. Two obvious features of the winged missile are the substantially higher lift curve slope throughout the Mach number range and the smaller variation in aerodynamic center location with Mach number. The differences in pitch control effectiveness are relatively insignificant. The instantaneous g capability for the winged missile with the aft tail control is shown in figure 12 as a function of Mach number of various altitudes and for an assumed loading W/A of 750 pounds per square feet. This particular missile indicates relatively high maneuverability in at least two regions of interest; one being the so-called dogfight missile region, where approximately 40 to 50 g's are indicated near an altitude of about 30,000 feet, and the other being at intercept altitudes above 70,000 feet at the higher Mach numbers where the missile still displays high g capability. An obvious feature for the wingless missile would be lower values of drag near zero lift, but this feature must be weighed against the increase in drag-due-to-lift for the case of maneuvering

flight. The wingless missile should be capable, however, in those regions where near ballistic fly-out paths can be used and where fast fly-out time is important. High g capability could be achieved at relatively low altitudes or at relatively high speed when significantly high dynamic pressure is experienced.

Two other missile configurations (results unpublished) are illustrated in figure 13 and represent two extremes in wing-body geometric design. A large volume missile with a relatively small wing and tail control was found to be highly maneuverable for conditions of low altitude and high Mach number and presumably would be well suited for tactical surface-to-surface or antishipping roles. Another possible mission for such a design would be an antishipping role for extended ranges where added range could be acquired through the use of a high-altitude, essentially ballistic, flight path. Sufficient control power was found to be available so that alterations to such a flight path could be made for the purpose of providing targeting accuracy greater than that available for pure ballistic flight. The configuration with the extremely large wing represents an attempt to provide high maneuvering capability at extremely high altitudes. Tests results indicated that the lift curve slope for this missile was approximately twice that of the winged missile shown in figure 11 with an increase in maneuvering capability particularly useful at extremely high altitudes provided the wing weight and drag is tolerable.

Observations related to wing control missiles. - Some results published in reference 57 are useful in demonstrating the characteristics of a wing control missile and in comparing these characteristics with a tail control concept (fig. 14). The configuration in reference 57 is essentially a Sparrow III with some results for the basic design with wing deflection for control with a fixed aft tail and some results with tail deflection for control with the wing fixed. The pitch control effectiveness of the wing was considerably less than that for the tail and was considerably more nonlinear. The wing control, by its nature, does produce a given lift at a lower angle of attack than does the tail control although the accompanying drag is considerably greater. All things considered, the wing control is inferior to the tail control in producing trim lift and normal acceleration. Whereas both the wing control and the tail control were capable of producing roll, that produced by the wing was quite nonlinear with angle of attack and was also accompanied by an induced yaw. Both the wing and tail controls were capable of producing yaw although the wing was much less effective; produced nonlinearities including reversal in yaw; and produced erratic induced roll. The underlying reason for the more erratic behavior of the wing control configuration is, of course, related to the flow field induced at the tail by the wing.

Generally speaking, a fundamental difference between wing controls and aft tail controls (or canard controls) is that the wing control produces a lift force near the center of gravity that provides more of a translating motion at relatively low angles of attack. Either aft or forward controls, on the other hand, produce a lift force at some distance from the center of gravity thus, providing a rotational motion that tends to add more lifting force from increasing angle of attack. The ability to maneuver sufficiently while still maintaining low angles of attack is, of course, a desirable objective since there would be some potential advantages related to seeker systems, airbreathing inlet efficiency, and induced flow field interference effects.

Some studies of missiles with relatively small wing controls (ref. 43, for example) indicate a high g capability at low altitudes. Longitudinal aerodynamic characteristics for this concept are shown in figure 15 for various control deflections at $M = 1.75$ and 2.50 . This concept is an airbreather with four inlets in a cruciform arrangement and uses all-moving wings for pitch and yaw control. The pitch-control effectiveness

is relatively high at the lowest Mach number but decreases very rapidly with increasing Mach number and increasing α . The lifting capability of the wing, of course, is related to the geometry of the wing. An examination of results for this configuration indicate that for $M = 1.75$ near sea level with a $W/A = 750$ pounds per square foot, sufficient lift can be developed to provide an a_n of 10 at $\alpha = 40^\circ$ and about $a_n = 21$ at $\alpha = 90^\circ$. Increasing M to 2.5 would result in a_n values of about 18 at $\alpha = 40^\circ$ and about 38 at $\alpha = 90^\circ$. An increase in altitude to about 40,000 feet reduces the a_n values for $M = 1.75$ to about 2.7 and 5.4 for $\alpha = 40^\circ$ and 90° , respectively. For $M = 2.5$ the a_n values would reduce to about 3.7 and 7.9 for $\alpha = 40^\circ$ and 90° . The α values of 40° and 90° used herein were determined partly on the basis of stability level limitations and partly on the need to maintain flow in the air inlets. The general conclusion from these comparative measures of maneuver potential is that this concept is well suited to perform missions at low altitudes where high a_n values are obtainable at low angles of attack but that this capability deteriorates severely at high altitudes.

The longitudinal aerodynamic characteristics for a higher altitude concept (refs. 19 and 23) are shown in figure 16 for various control deflections at $M = 4$. This concept is also an airbreather with an annulus inlet for ramjet propulsion and with somewhat larger wing controls than those employed on the low altitude concept. The results indicate good stability and control characteristics for α up to 200° . The air flow requirements for the annulus inlet are less sensitive to α , hence the maneuver potential for this concept was examined for $\alpha = 80^\circ$ and 200° . With a W/A of 750 pounds per square foot at $M = 4$, the values of a_n for $\alpha = 80^\circ$ were about 15 at 40,000 feet and about 2 at 80,000 feet. For $\alpha = 200^\circ$, these values increased to about 33 and 5 for altitudes of 40,000 feet and 80,000 feet. The general conclusion is that this concept, with high M capability and satisfactory wing geometry, is well suited for missions in the moderate to high altitude regimes and, of course, would have even greater maneuver capability if used at lower altitudes.

Other studies of a wing control missile with relatively large wing surfaces (ref. 46) have indicated the capability of performing the dogfight type role of approximately 40 to 50 g's near 30,000 feet at Mach numbers of about 3 and ability to perform well at altitudes up to about 70,000 feet against maneuvering targets.

Hinge-moment characteristics. - Hinge-moment measurements have been made on some of the control surfaces that have been discussed. Typical hinge-moment characteristics as a function of α and δ in the supersonic speed range are shown in figure 17. Such results have been obtained with forward-tail controls, mid or wing controls, and aft-tail controls. Desirable characteristics that have been noted are low values of C_h in the normal operating α range that translate directly into low torsional moments required to actuate the controls. Such characteristics should result in faster response time to control deflection and could potentially permit smaller, lighter, less expensive, and more reliable control actuators. Studies have indicated that these desirable hinge-moment characteristics are obtained by carefully tailoring the surface planform and by proper location of the control in the local flow field.

Observations related to cruise missiles. - Three types of cruise missiles are illustrated in figure 18. A cruise missile is considered to be a missile that is required to support its own weight in power-sustained level flight over a portion of its mission. Such things as distance and altitude of flight are functions of the required mission. The smallest of the three illustrated is an anti-tank concept and, in order for it to be visible in the sketch, it is shown at a relative scale twice that of the short- and long-range concepts. Although anti-tank missiles may not appear

appropriate to the cruise class of missile, when a typical mission of about 6500 feet range at an altitude of 3 to 6 feet is considered, it should be apparent that the cruise requirement is quite demanding. Unpublished results for the anti-tank concept at $M = 0.5$ indicated a trimmed lift-to-drag ratio of about 3 which would permit relatively heavy weights to be supported with low thrust. This performance was obtained by making use of a large, high aspect ratio wing to produce the lift required to support the weight and to offset the drag of the blunt forebody. A small canard surface was used to offset the moment produced by the large wing.

The short-range cruise-missile concept makes use of a fairly large volume body, a monoplane trapezoidal wing, and trihedral tail. Unpublished results indicate good aerodynamic characteristics with a geometric arrangement that provides for ease of storage and launch, and sufficient volume for the necessary internal systems to deliver warheads on the order of 1000 pounds for ranges of about 25 miles.

The long-range cruise-missile concept (ref. 50) employs a more efficient swept, monoplane wing and an increase in size, both of which contribute to longer range capability. Some results for a concept of this type are illustrated in figure 19. These results indicate a high drag-rise Mach number of about 0.95 that is achieved through careful attention to the component arrangement such that the transonic area distribution is essentially parabolic with the maximum cross-sectional area occurring at midbody length. Such an area distribution is theoretically optimum for minimizing the transonic drag rise. In addition, because of an inherent positive value of C_m at zero lift, the results indicated that the pitching moment can be trimmed with $\delta = 0^\circ$ at a lift coefficient for which the lift-to-drag ratio was maximum. Consideration of these aerodynamic characteristics indicates that a concept of this type can deliver a warhead on the order of 2200 pounds for ranges of 100 to 200 miles.

Hypersonic airbreathing missiles. - For the past several years, tactical and strategic hypersonic airbreathing missile concepts have been under study at Langley. These conceptual missile studies indicate that hypersonic airbreathing missiles have a unique potential for combining speed, range, and maneuverability in a relatively light-weight vehicle. These attributes, which are advantageous for both tactical and strategic missions, are achieved through the careful integration of the propulsion system with the airframe and the synergistic coupling of aerodynamic, propulsion, and structural disciplines. The evolution of tactical and strategic hypersonic missile concepts under study at Langley is included in reference 66 and a drawing of one of the concepts is shown in figure 20.

CONCLUDING REMARKS

A review of many missile configuration investigations coupled with the numerous possible mission requirements indicates that some fundamental considerations can lead to definite areas of missile/mission compatibility that is more of a science than an art. For example, a wingless missile or a missile with relatively small wings may take advantage of low minimum drag and accomplish missions where fast fly-out time is important. Such missiles, however, are generally not satisfactory from a maneuverability standpoint except under conditions of relatively low altitude and/or high speed, or when nearly ballistic fly-out paths can be used against essentially non-maneuvering targets.

When high maneuverability is required at any altitude or for high altitude interception of evasive targets, an efficient lifting surface is advantageous together with linear stability characteristics and high control effectiveness. It has been found that these criteria can be met with various design arrangements that may employ aft tail, wing, or canard controls. It has also been found that, through careful design, each of these control types can result in desirably low hinge-moment characteristics.

Carefully designed wing control missiles may provide adequate maneuverability at relatively low angles of attack for some missions while offering potential advantages related to seekers, air inlets, and induced flow fields.

Cruise missile configurations vary somewhat in detail but the dominant factor is an aerodynamically efficient design that is commensurate with the required weight and the desired range.

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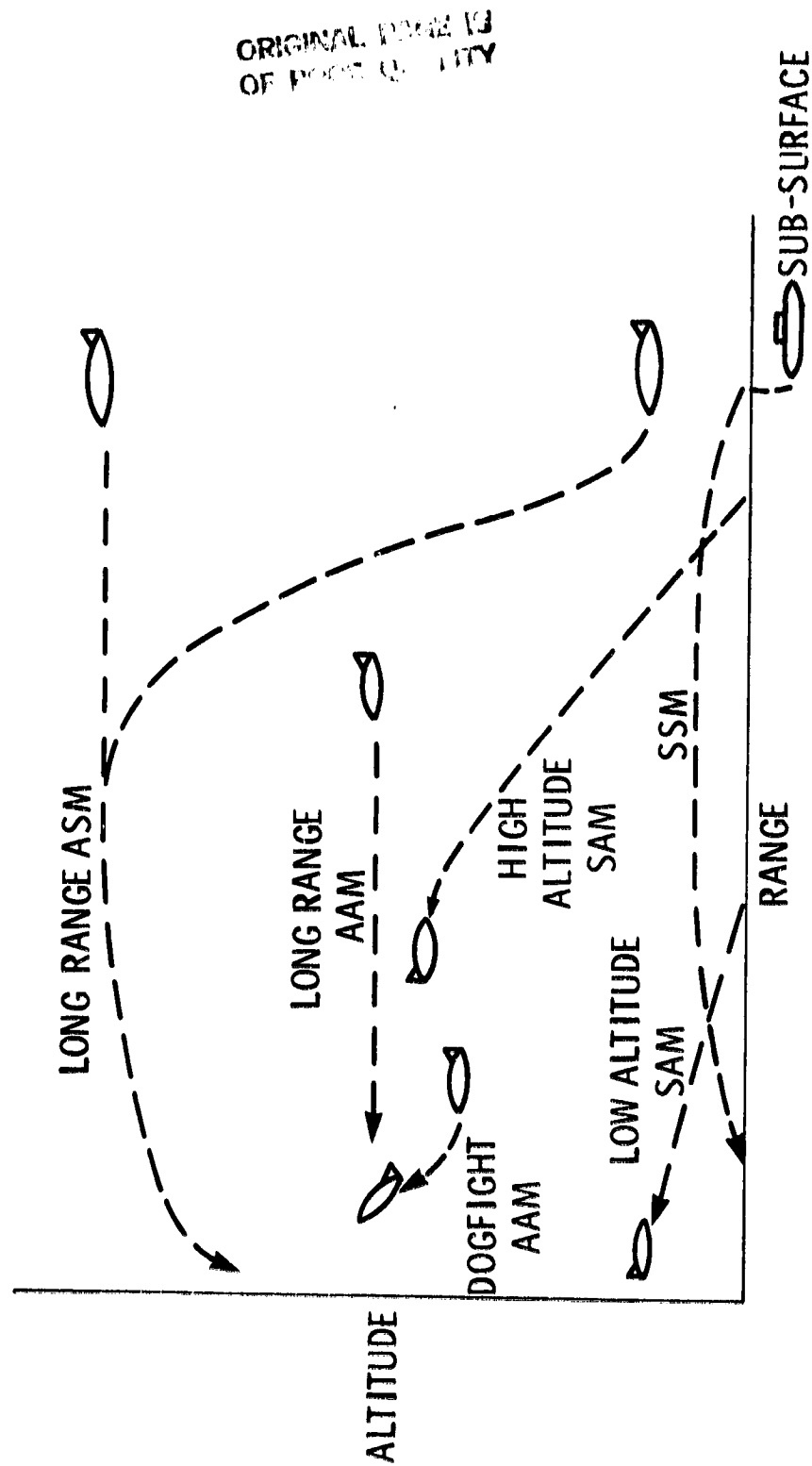


Figure 1.- Types of missile missions.

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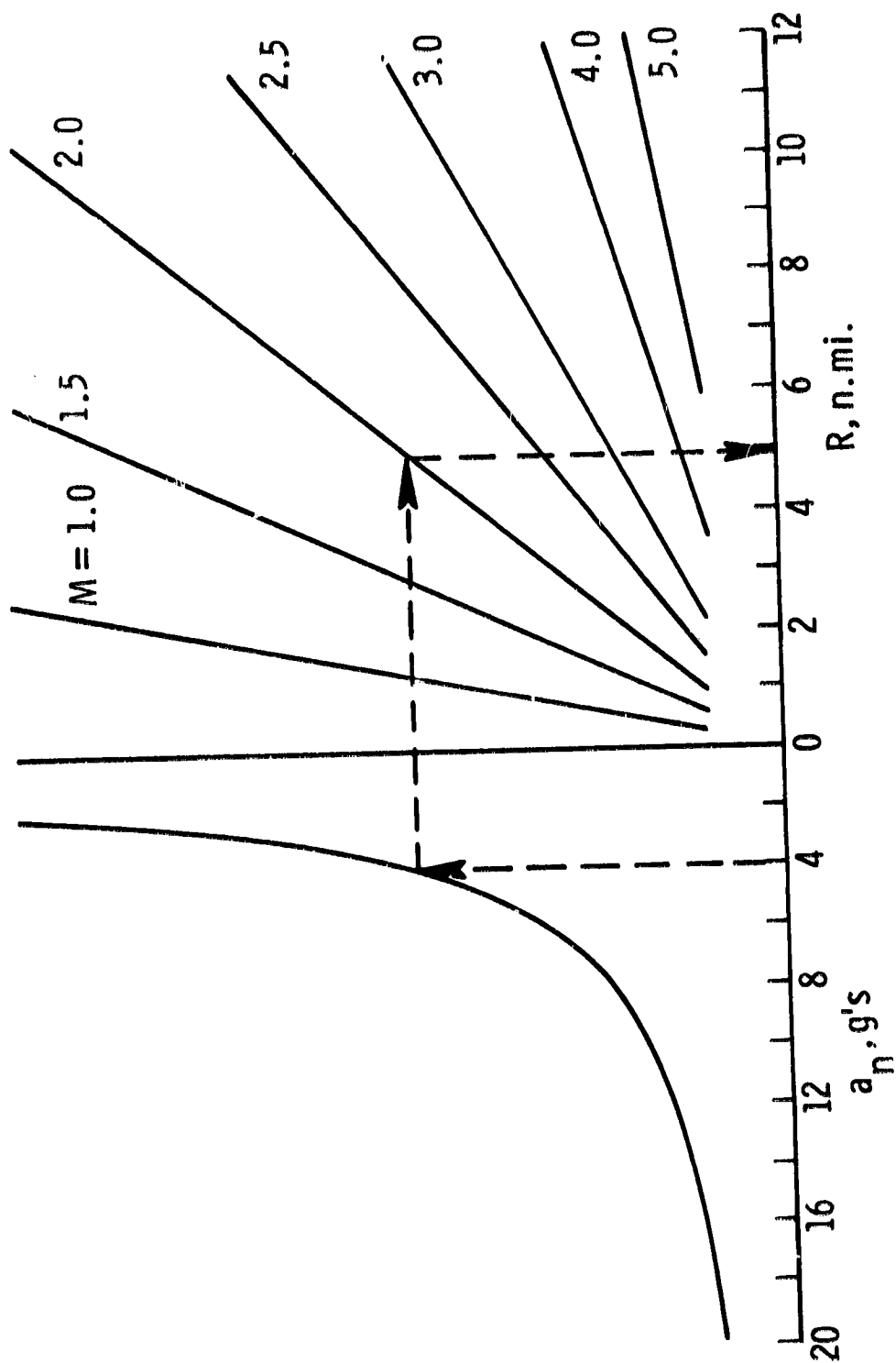


Figure 2.- Factors affecting turn radius.

$M = 2.4, h = 30000 \text{ ft}$
 a_n H.M. W/S
 FLAP 6.3 1000 in. lb 93
 CANARD 16.0 80 in. lb 180

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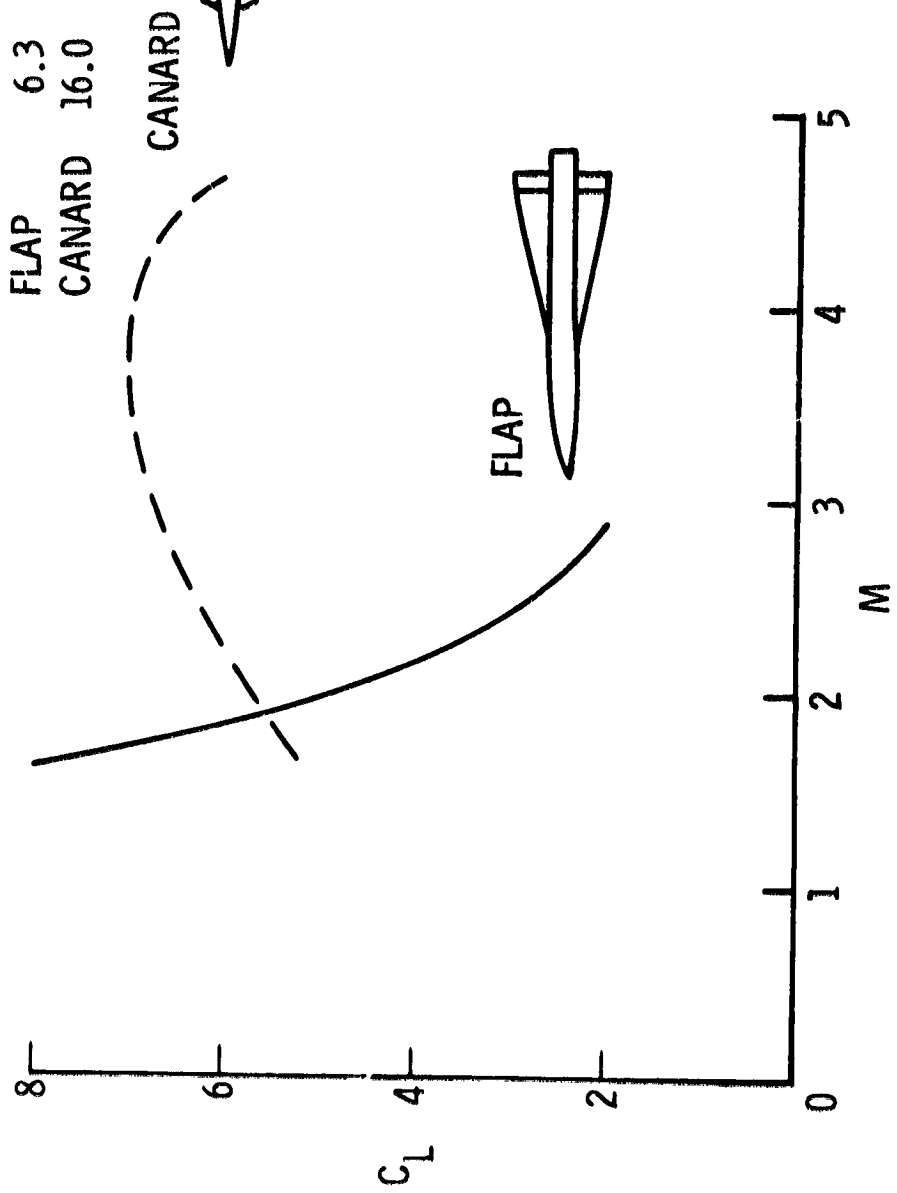


Figure 3.- Maximum lift capability.

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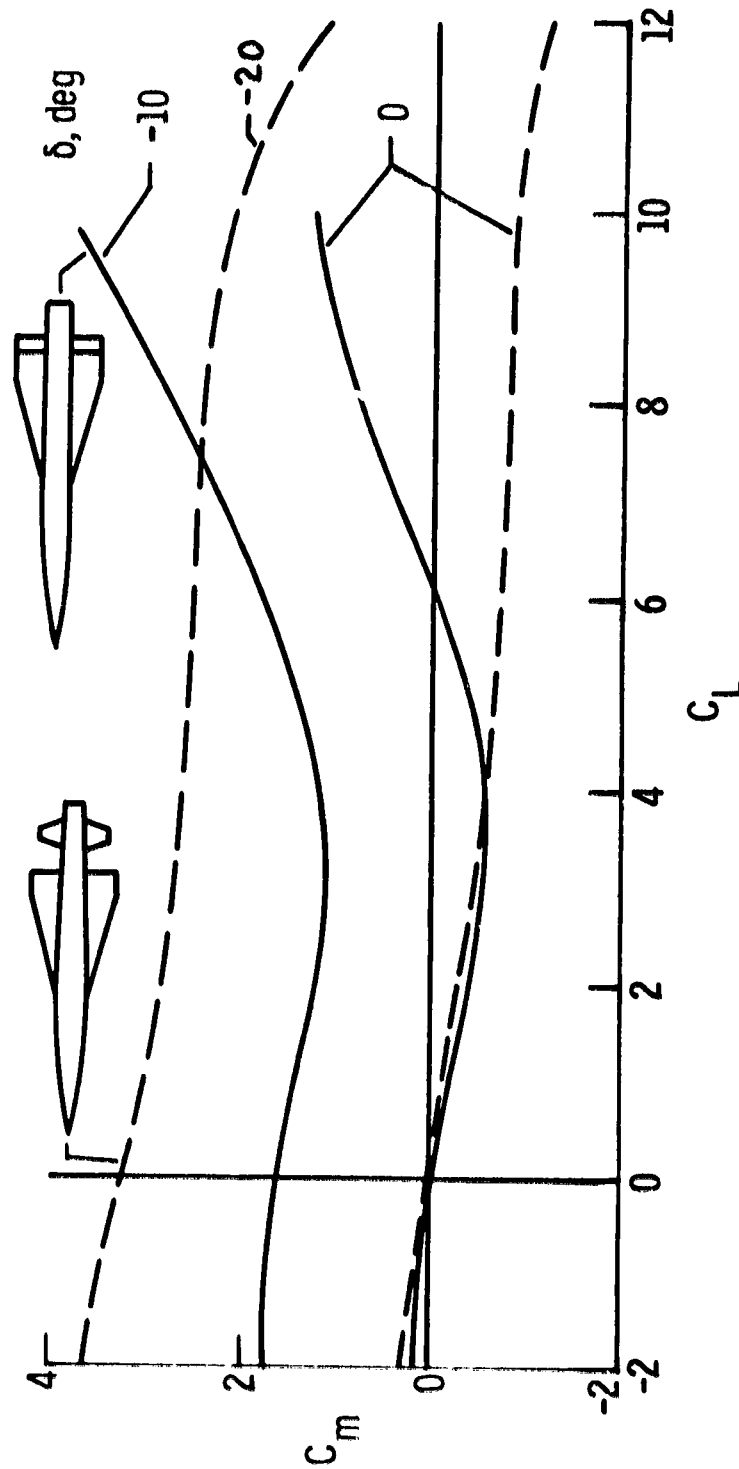


Figure 4.- Comparison of aft tail and flap control; $M = 3$.

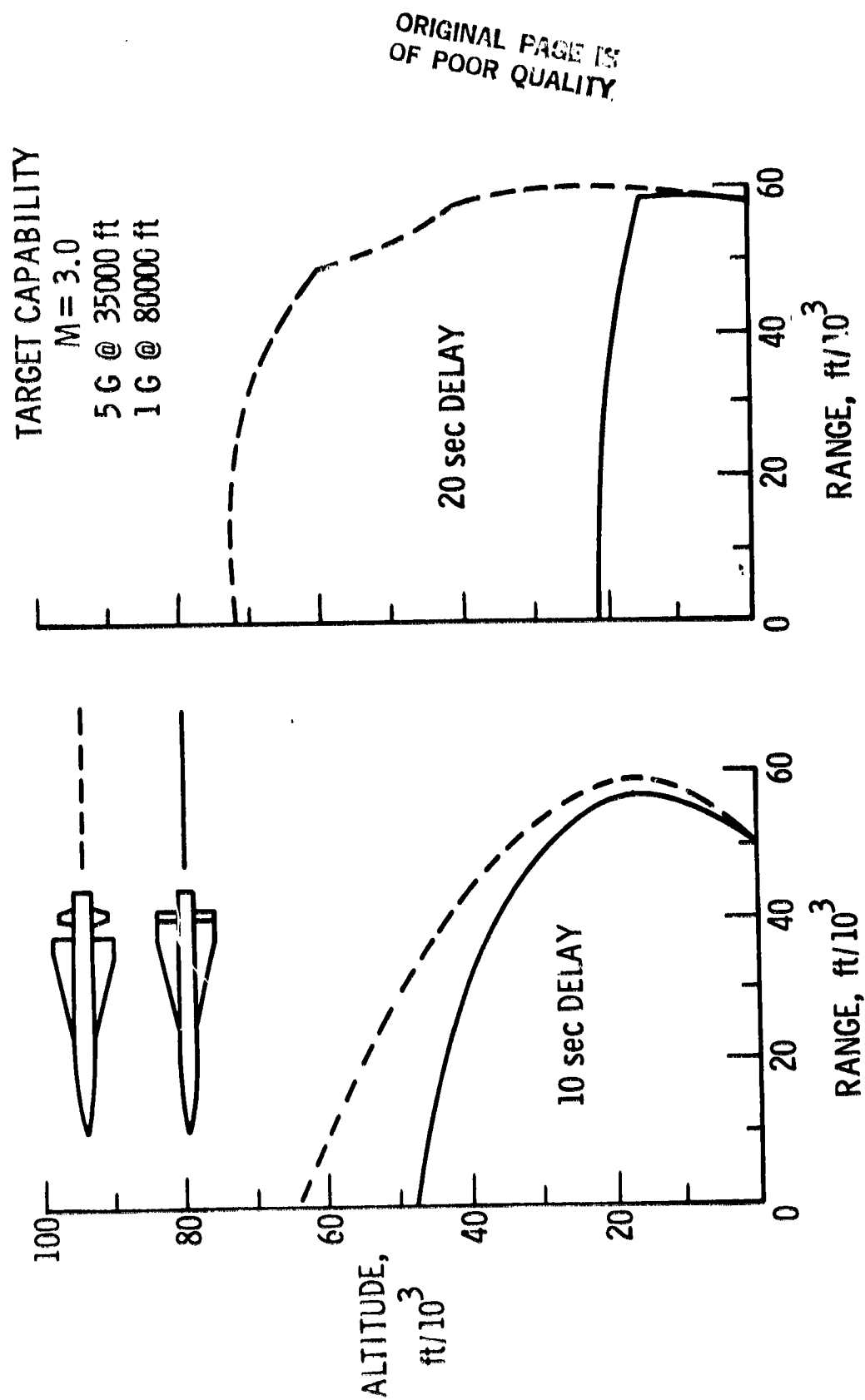


Figure 5.- Effective missile operating envelopes.

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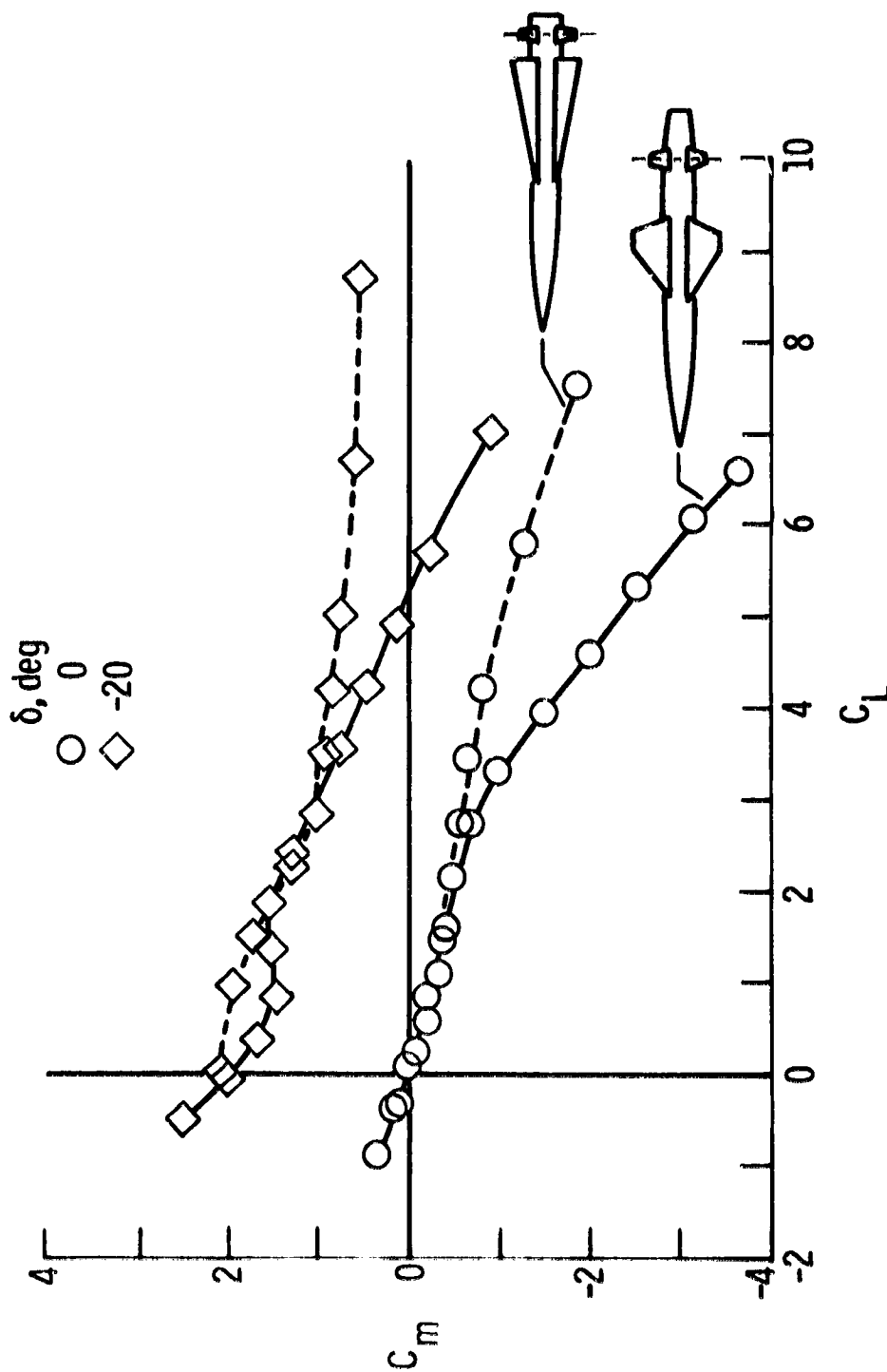


Figure 6.- Configuration effects with aft tail; $M = 4.6$.

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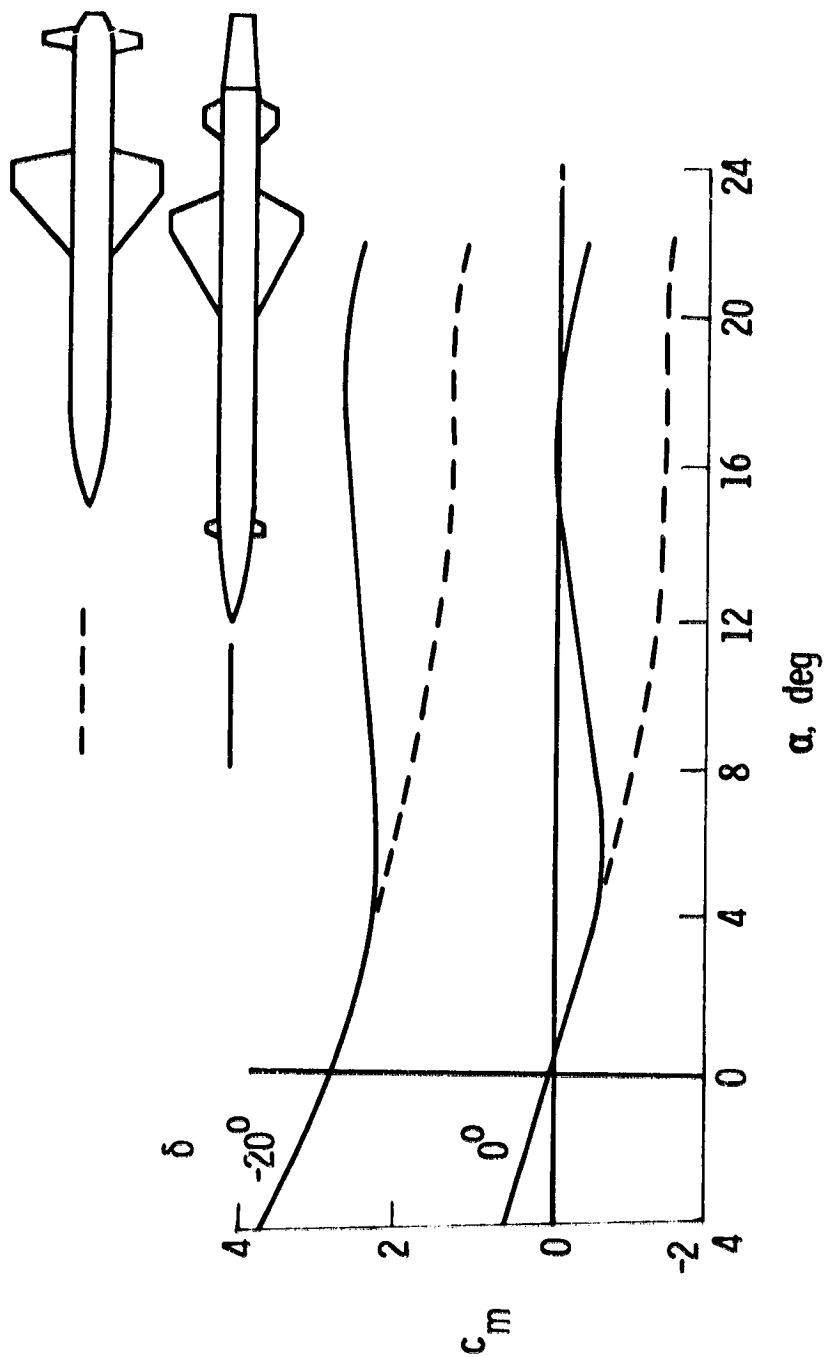


Figure 7.- Longitudinal characteristics for two aft-tail control concepts.
 $\dot{\alpha} = 45^\circ$, $M = 3$.

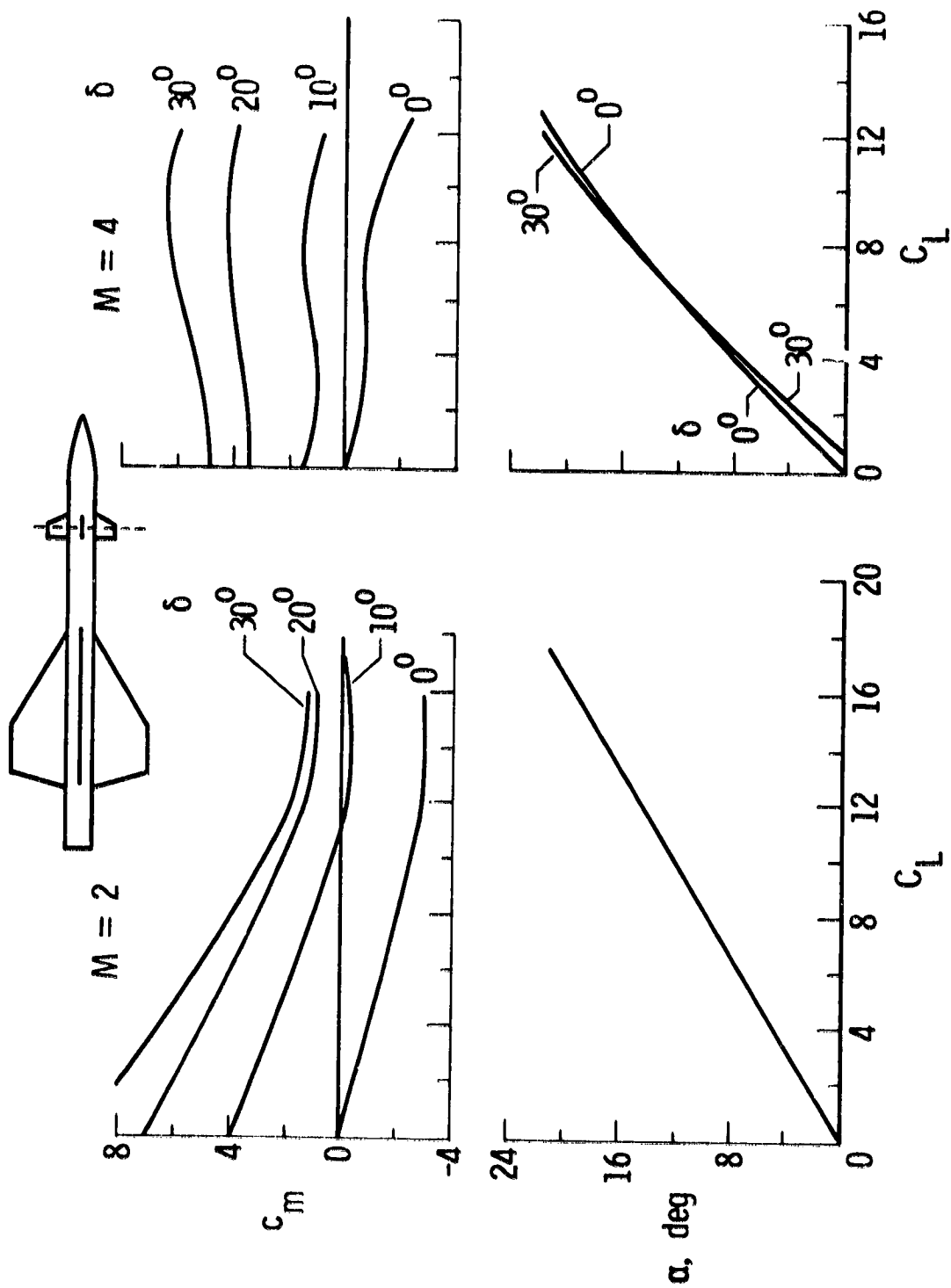


Figure 8.- Longitudinal characteristics for a canard concept. $\delta = 0^\circ$,
 $M = 2$ and 4 .

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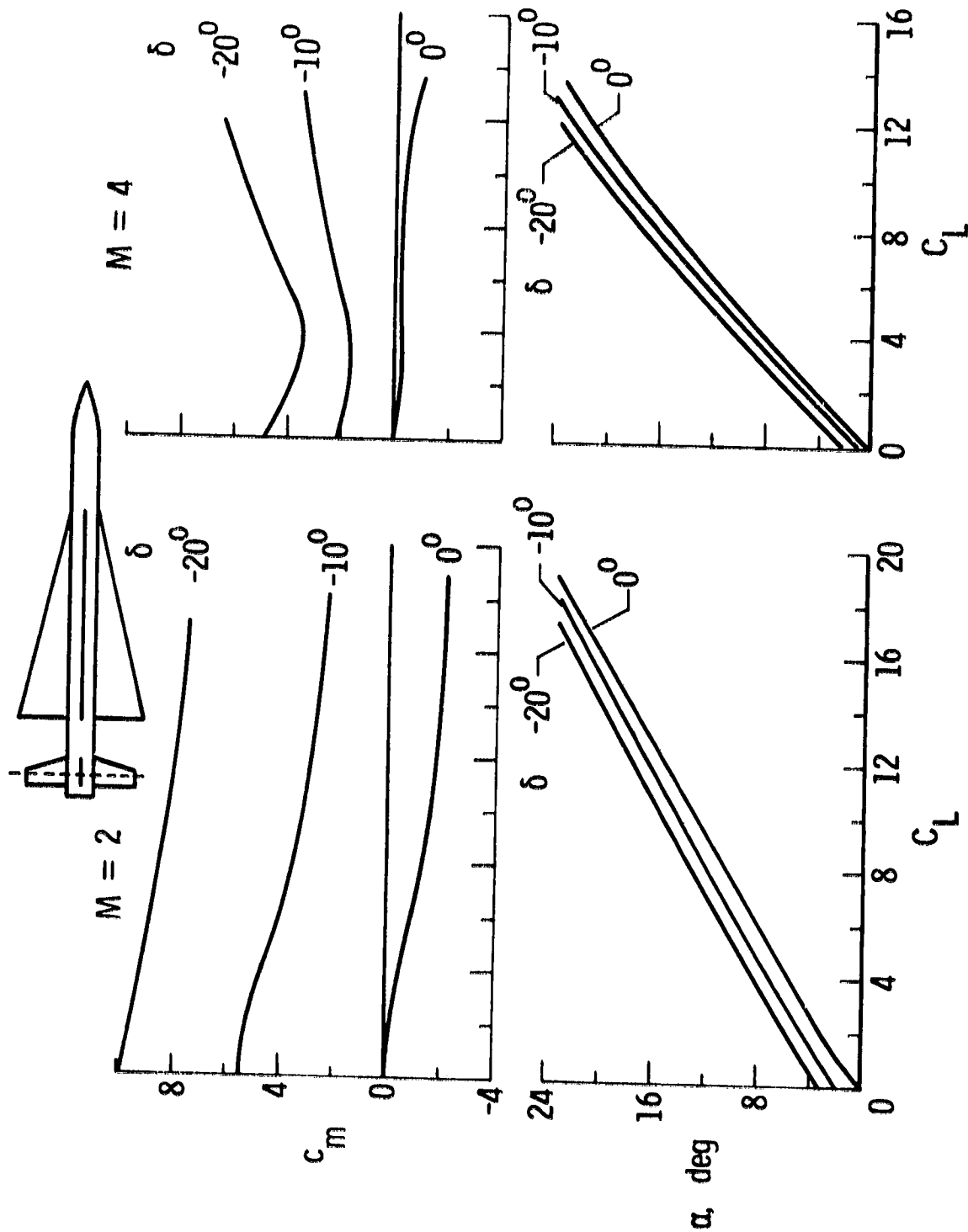
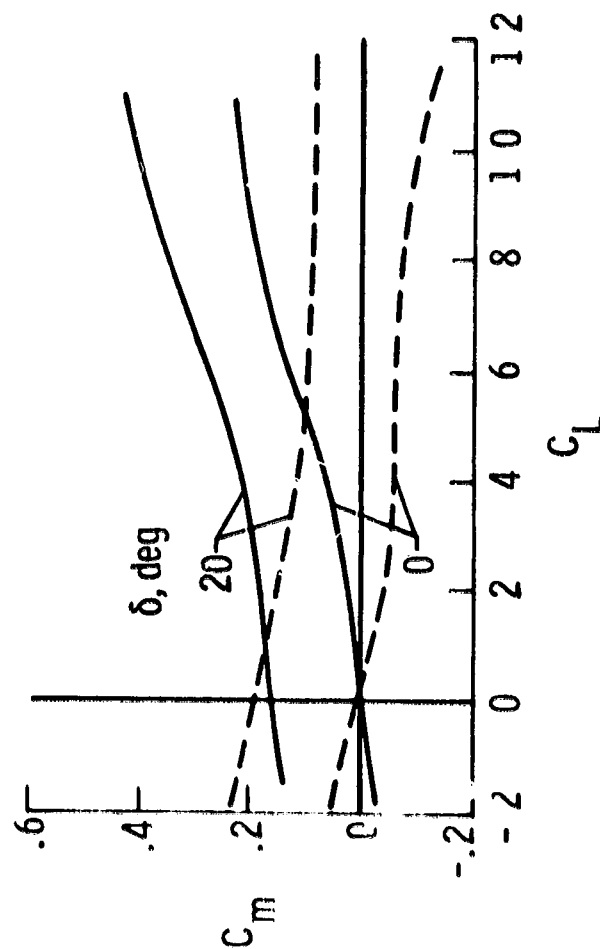


Figure 9.- Longitudinal characteristics for an aft-tail control concept.
 $\phi = 0^\circ$, $M = 2$ and 4.



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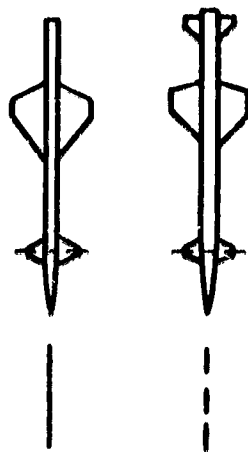


Figure 10.- Configuration effects with canard control; $M = 3$.

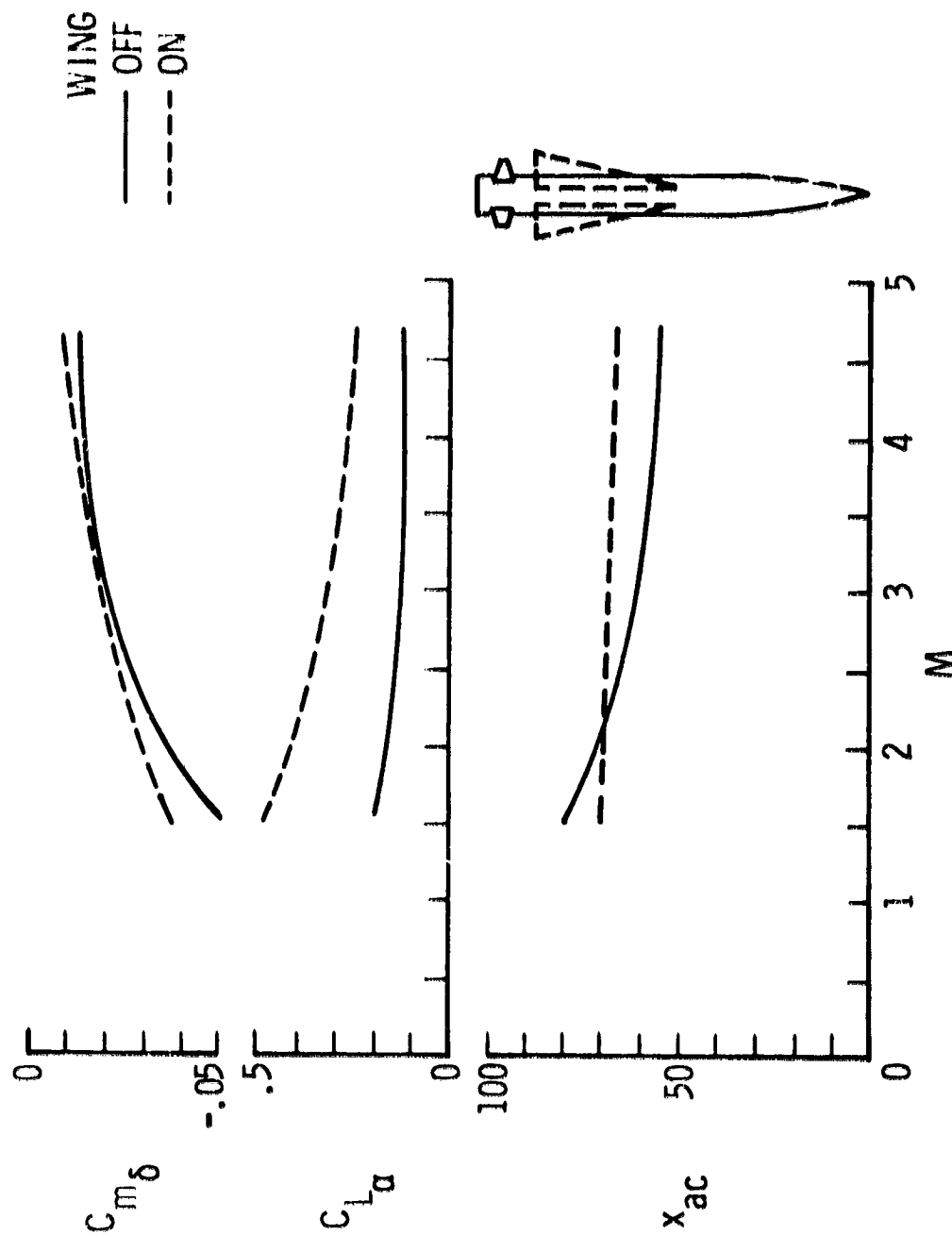


Figure 11.- Wing effect with aft tail.

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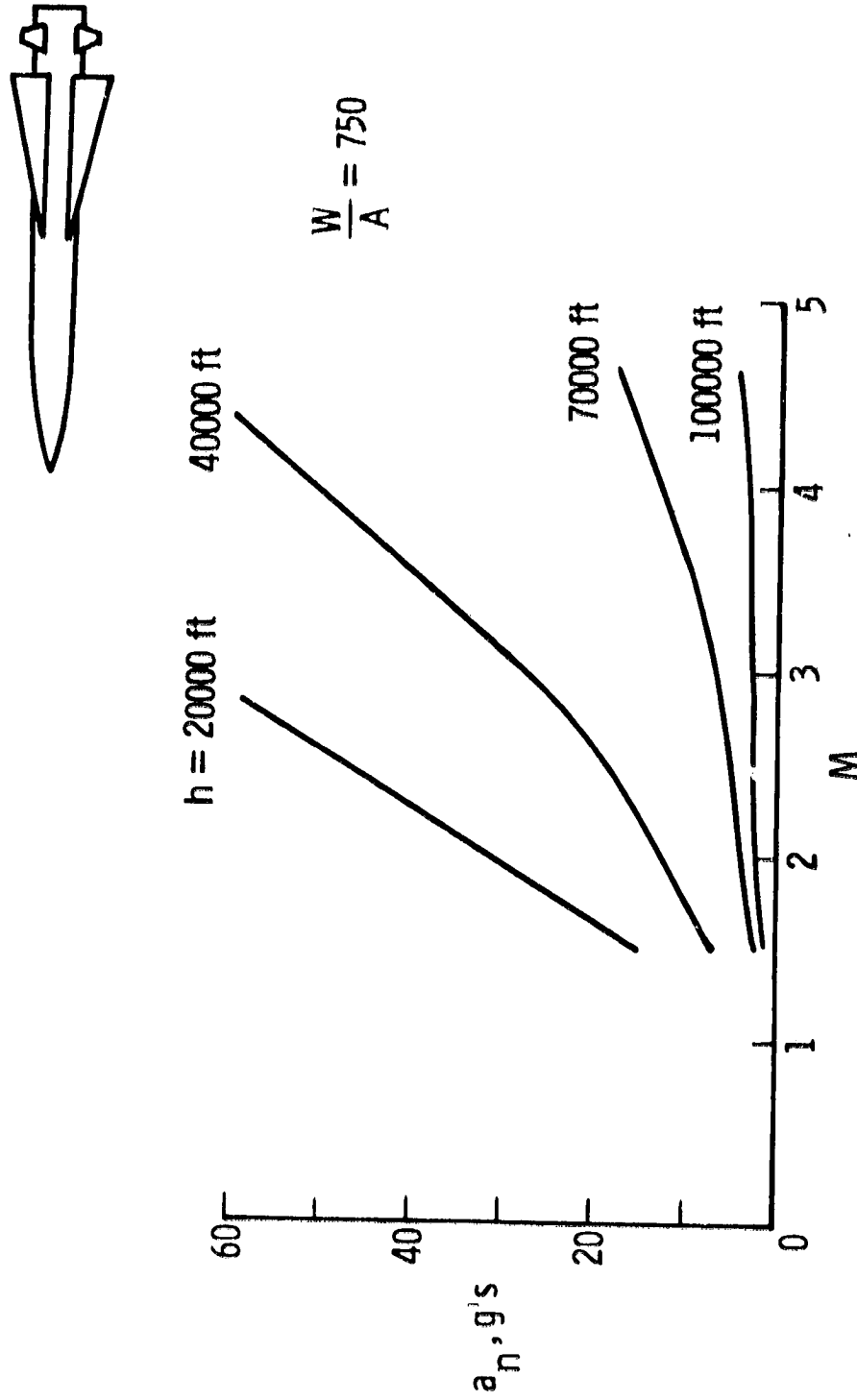
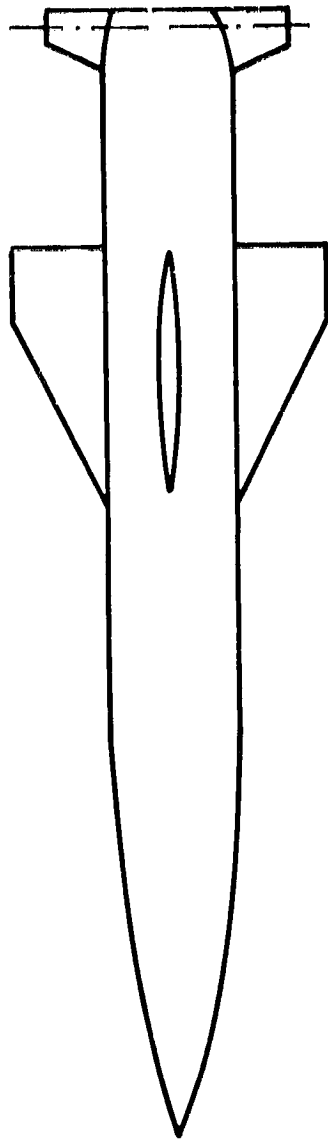
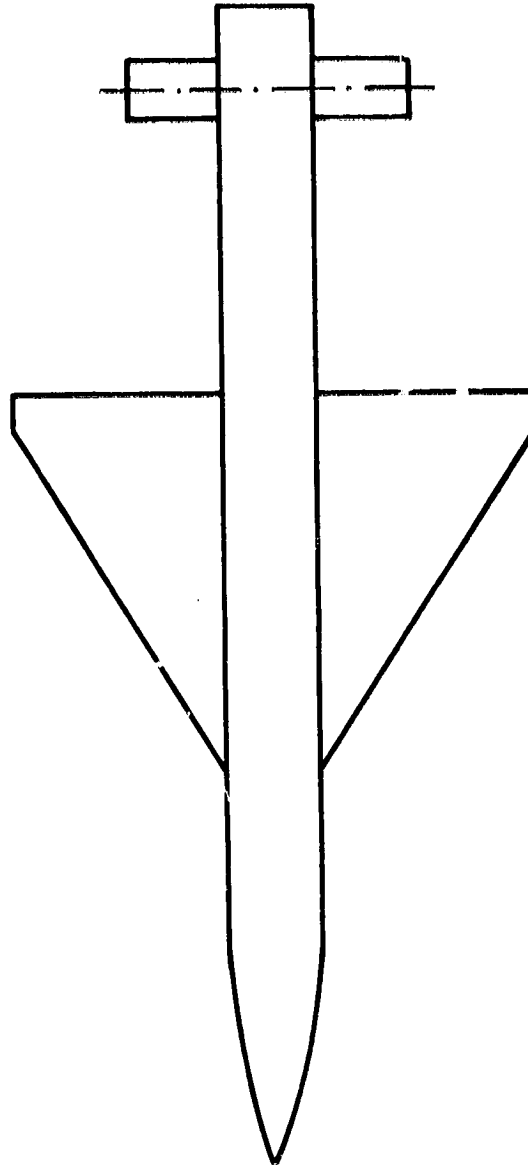


Figure 12.- Maneuver capability for delta wing aft tail.

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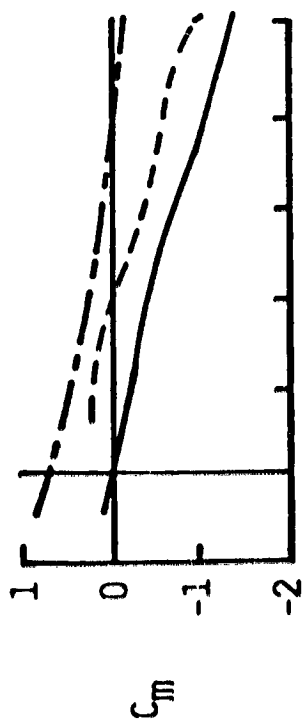
HIGH VOLUME MISSILE



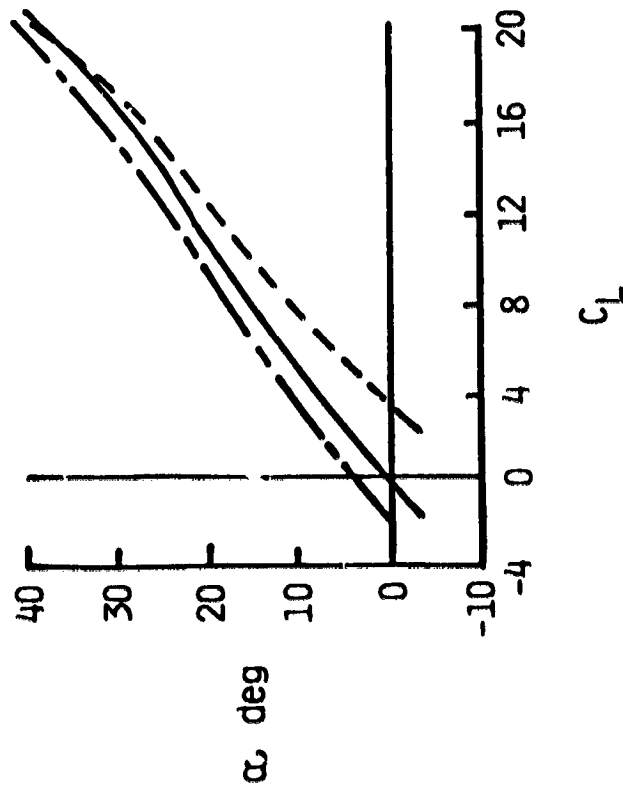
HIGH ALTITUDE MISSILE

Figure 13.- Missile concepts.

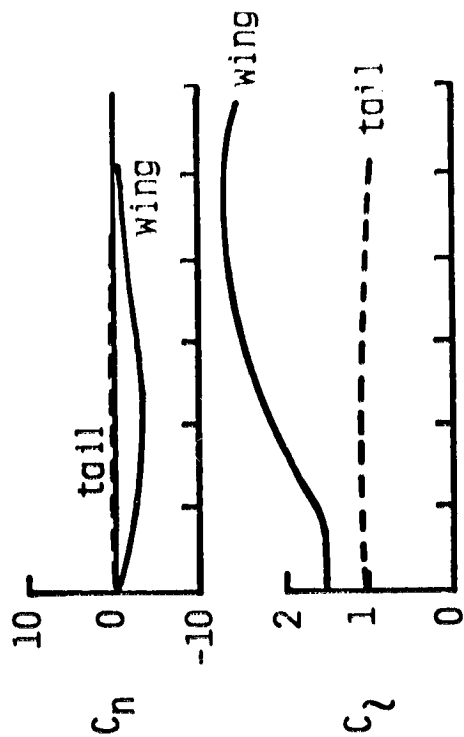
Pitch control



— wing, tail, $\delta = 0^\circ$
 - - - wing, $\delta = 20^\circ$
 - . - tail, $\delta = -20^\circ$



Roll control, $\delta = 10^\circ$



Yaw control, $\delta = 10^\circ$

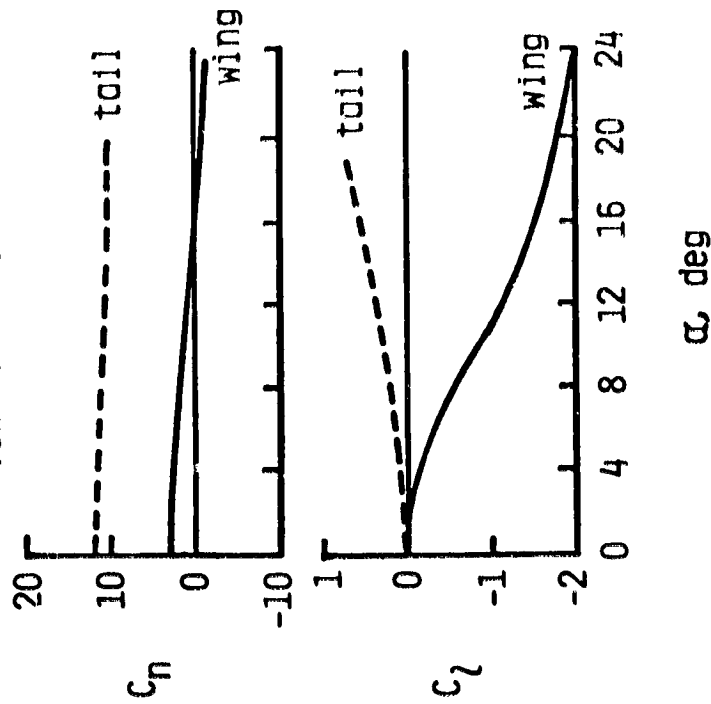


Figure 14.- Comparison of wing and tail control. $M = 2.87$.

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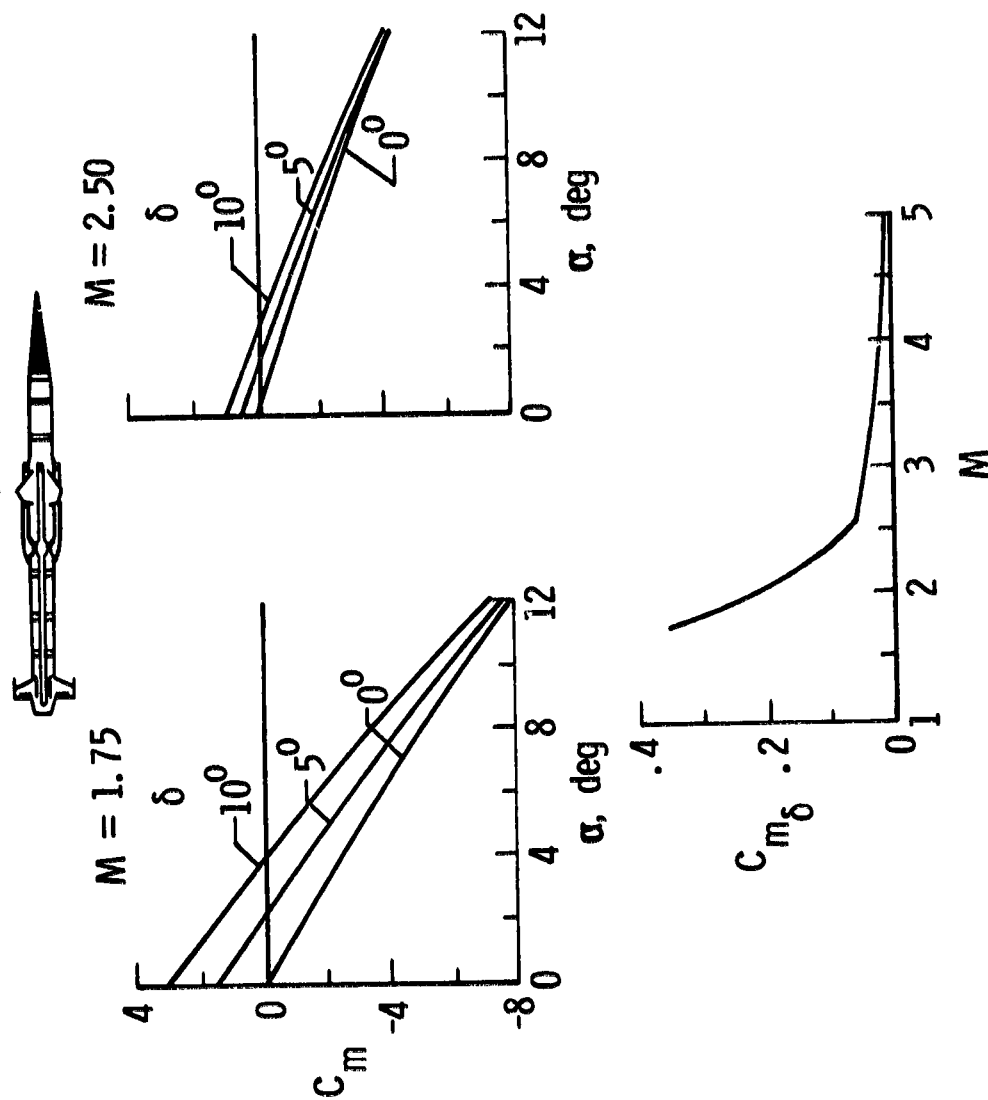


Figure 15.- Longitudinal characteristics for a low-altitude wing-control concept. $\phi = 0^\circ$, $M = 1.75$ and 2.50 .

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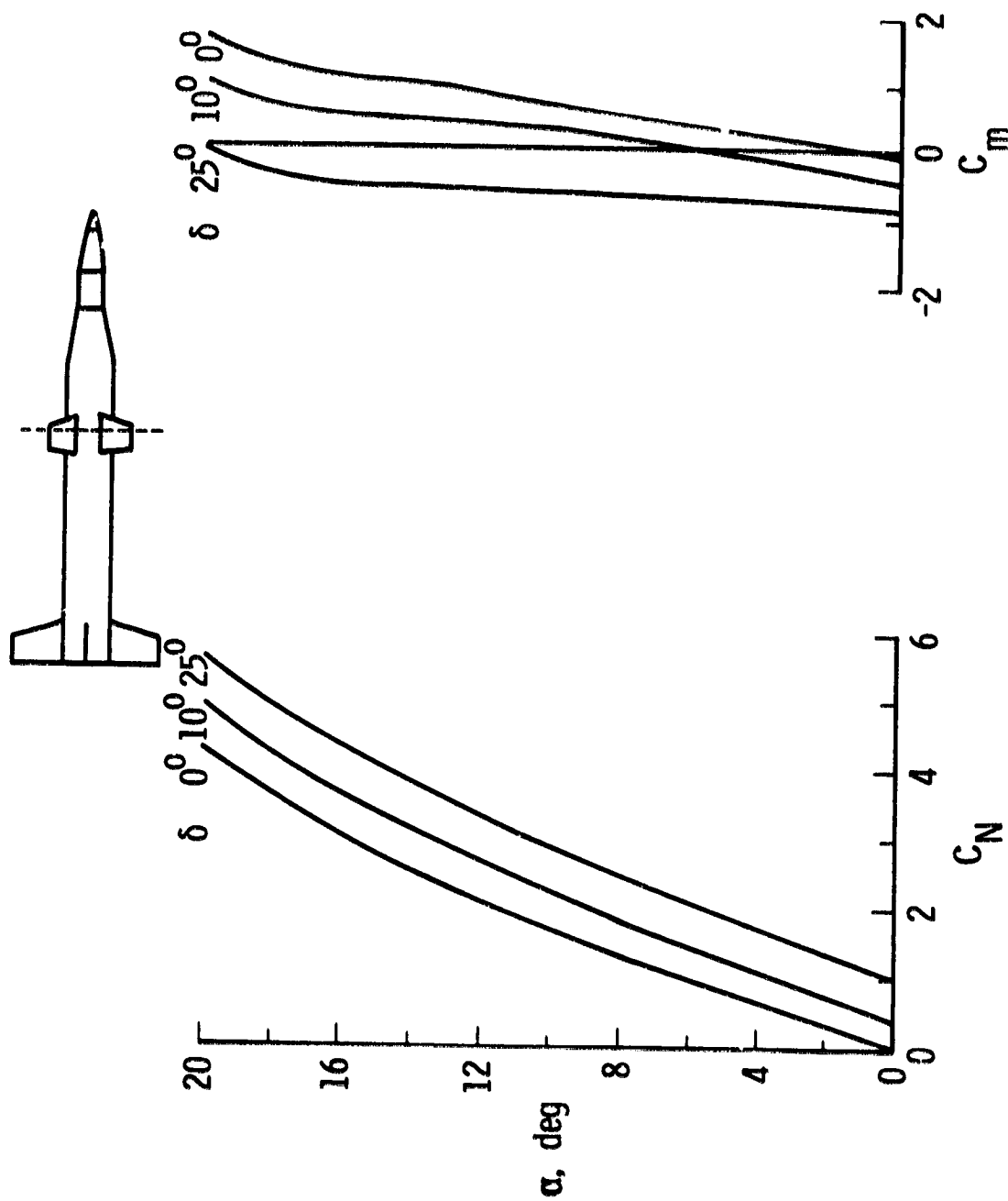


Figure 16.- Longitudinal characteristics for a high-altitude wing-control concept. $\phi = 0^\circ$, $M = 4$.

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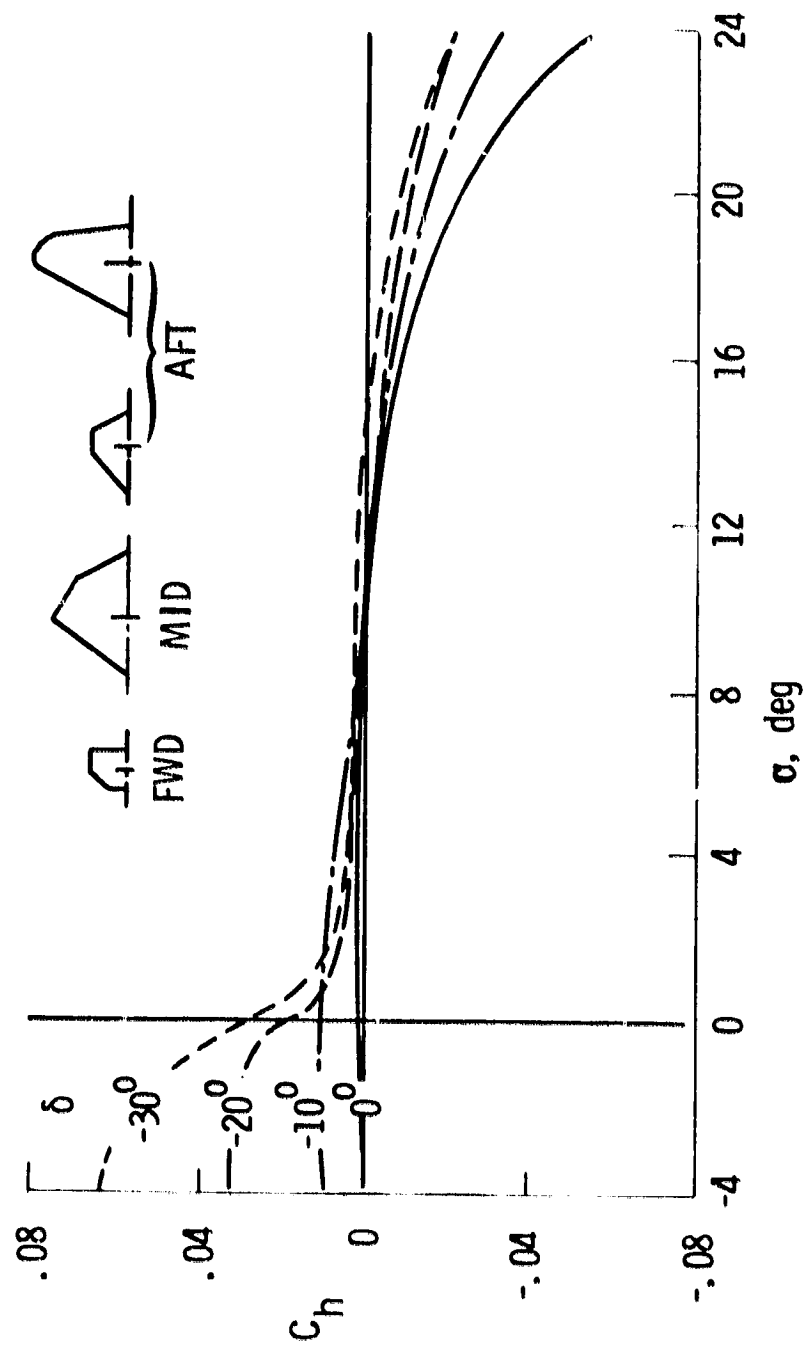
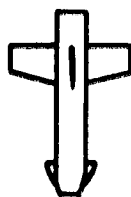
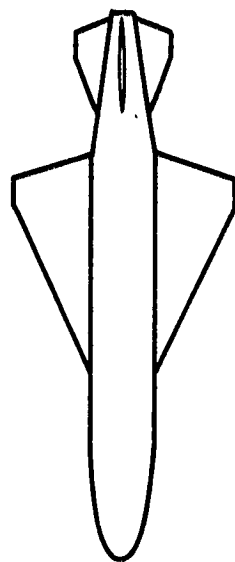


Figure 17.- Typical control hinge-moment characteristics at supersonic speeds.

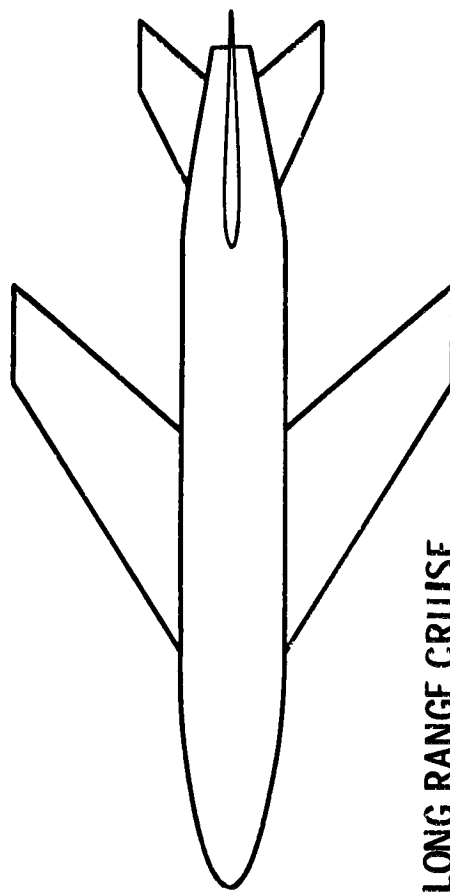
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ANTI-TANK



SHORT RANGE CRUISE



LONG RANGE CRUISE

Figure 18.- Cruise missile concepts.

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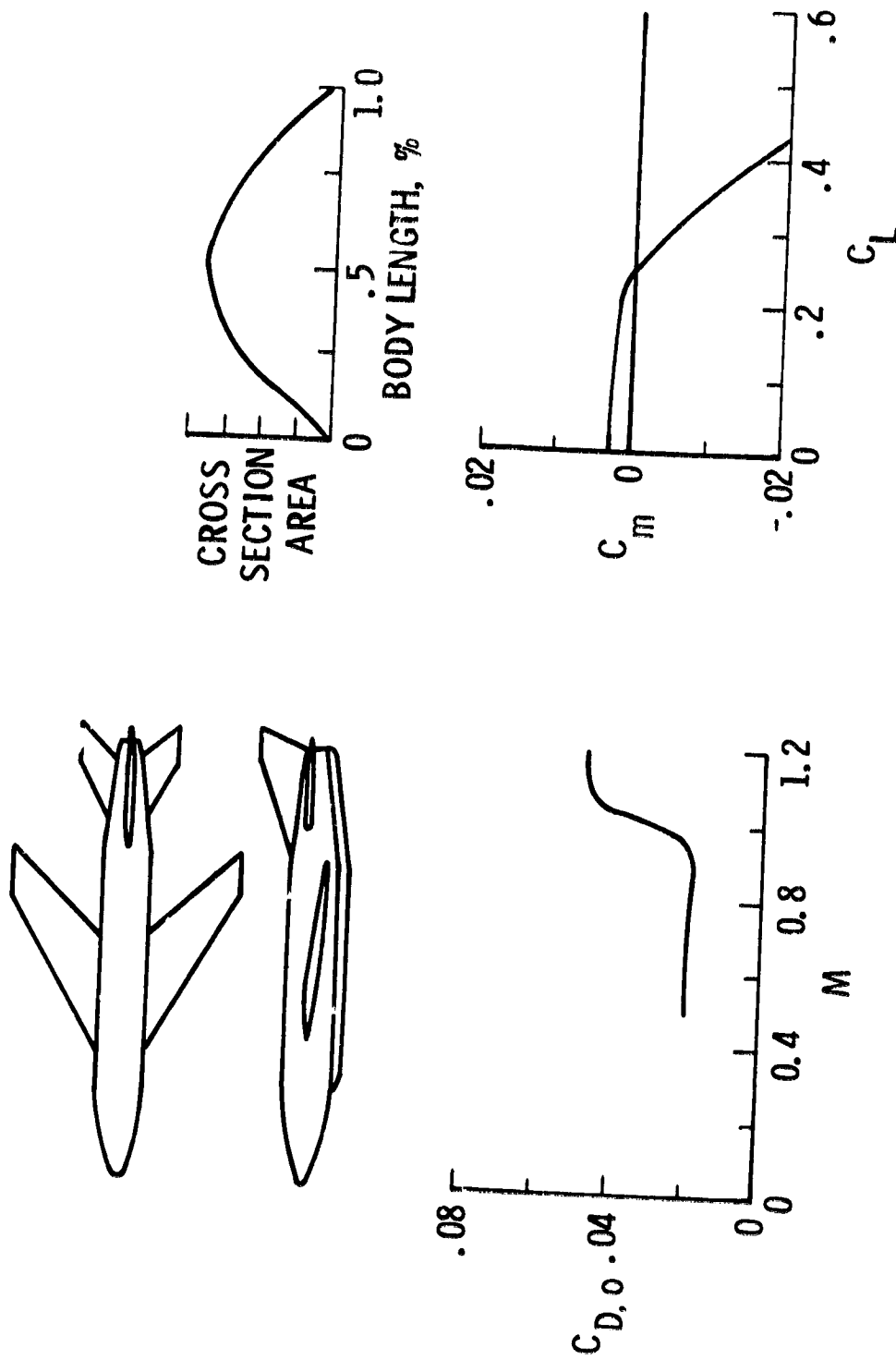


Figure 19.- Longitudinal characteristics for a cruise missile concept.

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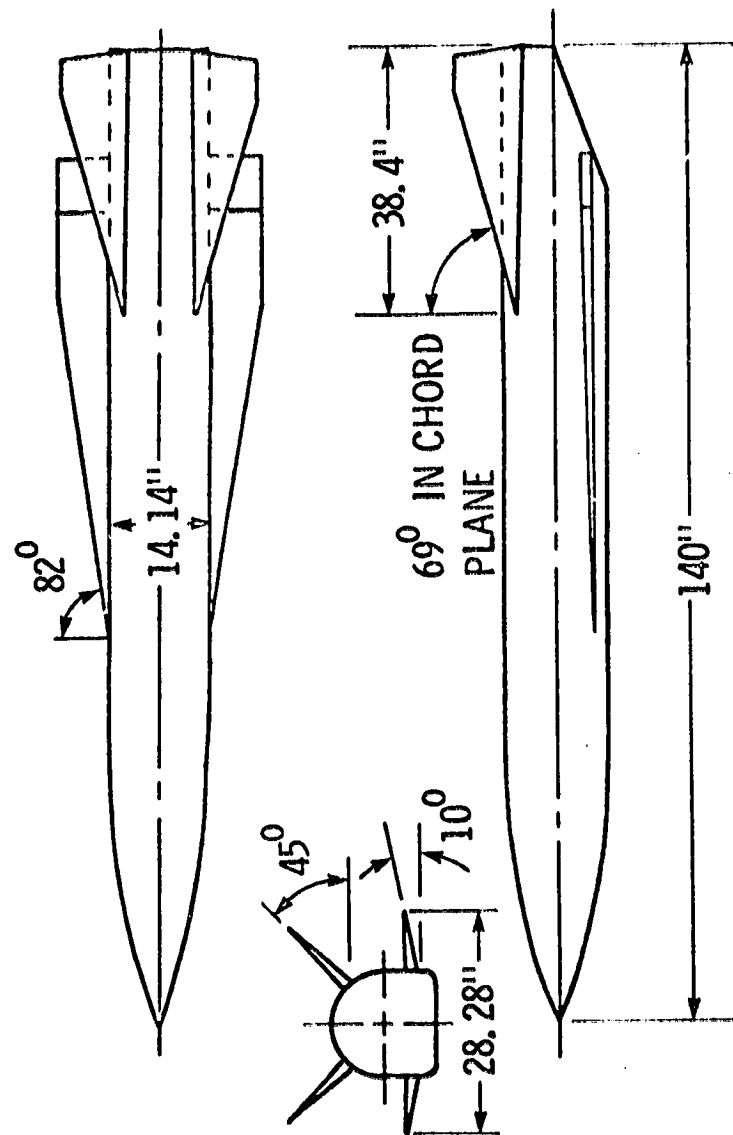


Figure 20.-- Hypersonic missile configuration.